



Advanced Space Propulsion: A Research Perspective

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Advanced Space Propulsion Research

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Interpretation of Administrator's Vision & Focus

One NASA — Centralize Program Management & Budgets at HQ

Reshape NASA into a premier R&D agency

- *Emphasis on R&D*
- *Develop cutting edge technologies that overcome current limits — e.g., NSI*

Align with President's Management Agenda

- *Competitive Sourcing* — seek the best outcome (public or private)
 - *Strategic Planning* — allocate resources to affect desired outcomes
 - *Strategic Management of Human Capital* — insure agency competency
 - *Financial Management Discipline* — restore realism, credibility, and accountability
- Emphasis on interagency relationships where it makes sense
- *Alignment with DOD, DOE, DOC, DOT, etc.*

**“To understand and protect our home planet, to explore the Universe
and search for life, to inspire the next generation of explorers
... as only NASA can”**



The Need for Space Propulsion Research

Space transportation capability is limited by available propulsion technologies

- *Space launch payload fraction is constrained by today's propulsion system capability*
- *Practical deep space exploration requires highly energetic propulsion & power systems*
- *Conventional chemical propulsion has reached its natural plateau of available energy*
- *Revolutionary advancement will require research into new propulsion methods*

Currently, the agency has no coordinated low TRL propulsion research program

- *NGLT research hole — No TRL 1-3 feeders*
- *In-Space & NSI research hole — No TRL 1-3 feeders*
- *Exploration research hole - No highly enabling TRL 1-3 feeders*
- *The agency has no program for revolutionary propulsion research in FY03 and beyond*
- *Many system studies are being conducted with little or no insight into emerging technologies*
- *Need stable research environment ⇒ "A necessity of success is constancy of purpose"*

Strategic Planning mandate should also apply to space propulsion research

- *Coordinate efforts within broader scope of ISTP*

Space propulsion research is a unique NASA role

- *NASA's needs go far beyond the needs of other government agencies*
- *High risk dissuades commercial sector from making significant long-term research investments*

Propulsion Research Drivers for Space Access

◆ Increase payload by reducing fuel fraction

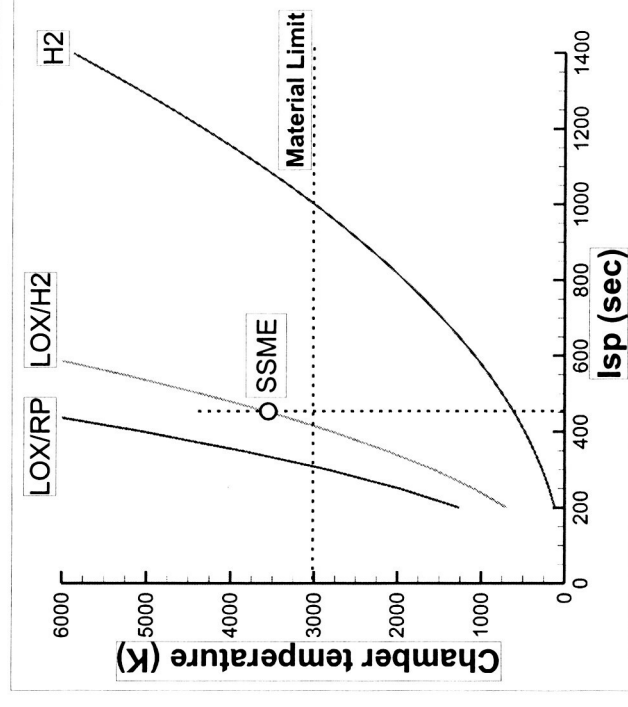
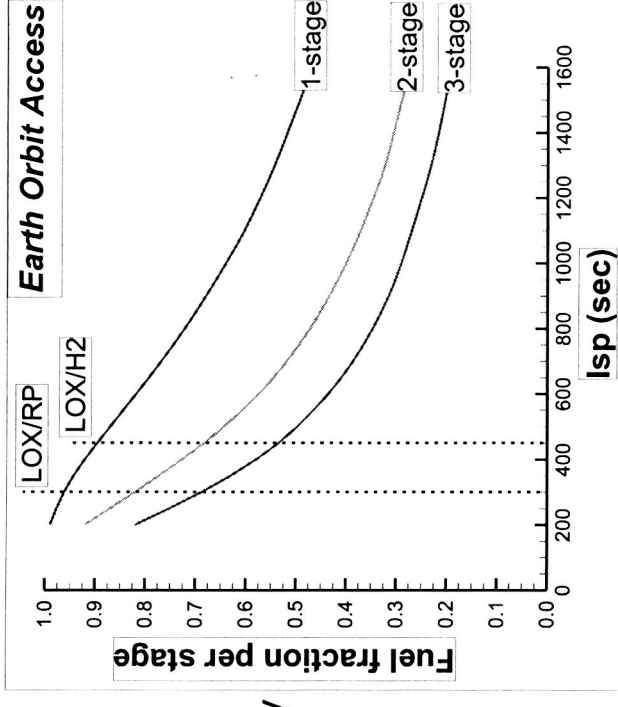
- Requires higher specific impulse (i.e., specific energy)
- Chemical propulsion has limited specific energy
- Need improved energetics in order to make revolutionary advances in propulsion capability

◆ Thermal propulsion is constrained by material temperature limits

- Increased performance implies:
 - Higher chamber temperatures and/or decreased molecular weight
 - Increased component efficiencies and/or decreased inert dry weight
- LOX/Hydrogen near thermal limits
 - Near maximum chemical energy density
 - Near minimum molecular weight
 - Pushing material temperature limits
- Need innovative methods for bypassing thermal constraints

◆ Promising avenues of research exist, such as

- Highly energetic fuels
- New engine cycles
- Electromagnetics/Beamed Energy



Propulsion Research Drivers for Deep Space Transport

◆ In-Space Transportation Challenges

- The fundamental technical obstacles to deep space (beyond Mars) transportation are related to propulsion energetics

- Specific Energy
 - low IMLEO demands high Isp propulsion
- Specific Power
 - short trip times demand high Δv maneuvers (i.e., high jet power for high acceleration)

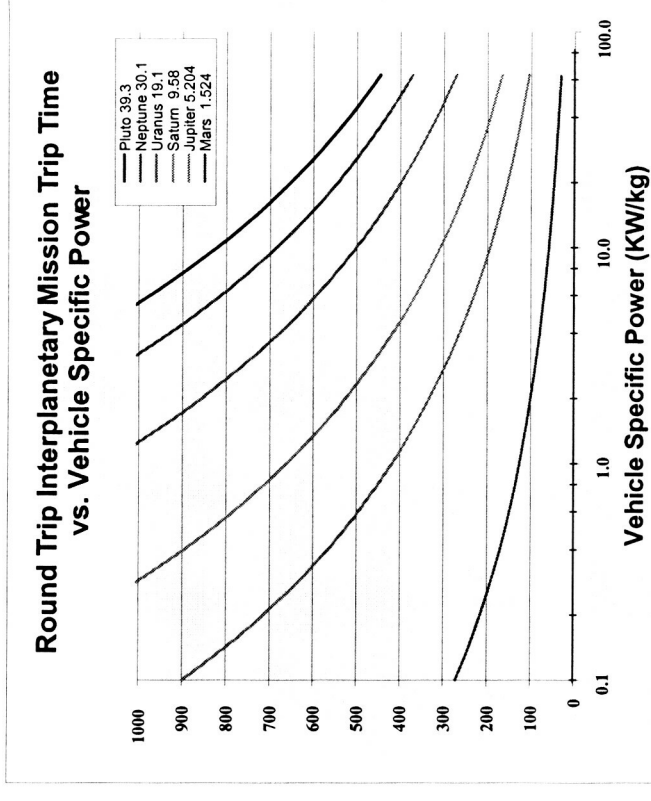
- Affordable, short-duration, on-demand travel beyond Mars will require robust performance margins

- Order of magnitude increase in specific energy
 - delivered mass fraction > 50%
- Specific Power ~ 10 kW/kg
 - outer-planet round trips measured in days rather than years

- Requirements far beyond our current plans for Nuclear Electric Propulsion (~0.03 kW/kg)

- Potential research avenues

- Advanced closed-cycle nuclear electric propulsion best near-term prospect
- Fission offers good long-term prospects
- Beamed energy and sails may help
- Component research also needed (high-temperature radiators / flight-weight magnets)
- Breakthrough propulsion physics (new scientific discoveries)



**... must break through 1 kW/kg barrier
and ultimately approach ~ 10 kW/kg**

Desired Propulsion Research Outcomes

◆ Capability

- The fundamental limits associated with current propulsion systems demand the pursuit of highly energetic propulsion technologies
- However, the pursuit of ever more energetic propulsion systems must be balanced against other attributes affecting risk and affordability
 - Trades between energetics and hazards
 - Understanding of potential failure modes
 - Development of materials compatible with harsher operating environments

◆ Durability

- Increased performance capability implies more energetically stressed parts/components
- Acceptable system durability can only be achieved with vigorous materials research support and thorough understanding of component failure mechanisms

◆ Maintainability

- Need tighter integration of propulsion systems with airframe/spacecraft, but designs must allow rapid component change out to insure vehicle availability
- Greater reliance on advanced health monitoring diagnostics for identifying maintenance actions but not at the risk of compromising vehicle reliability

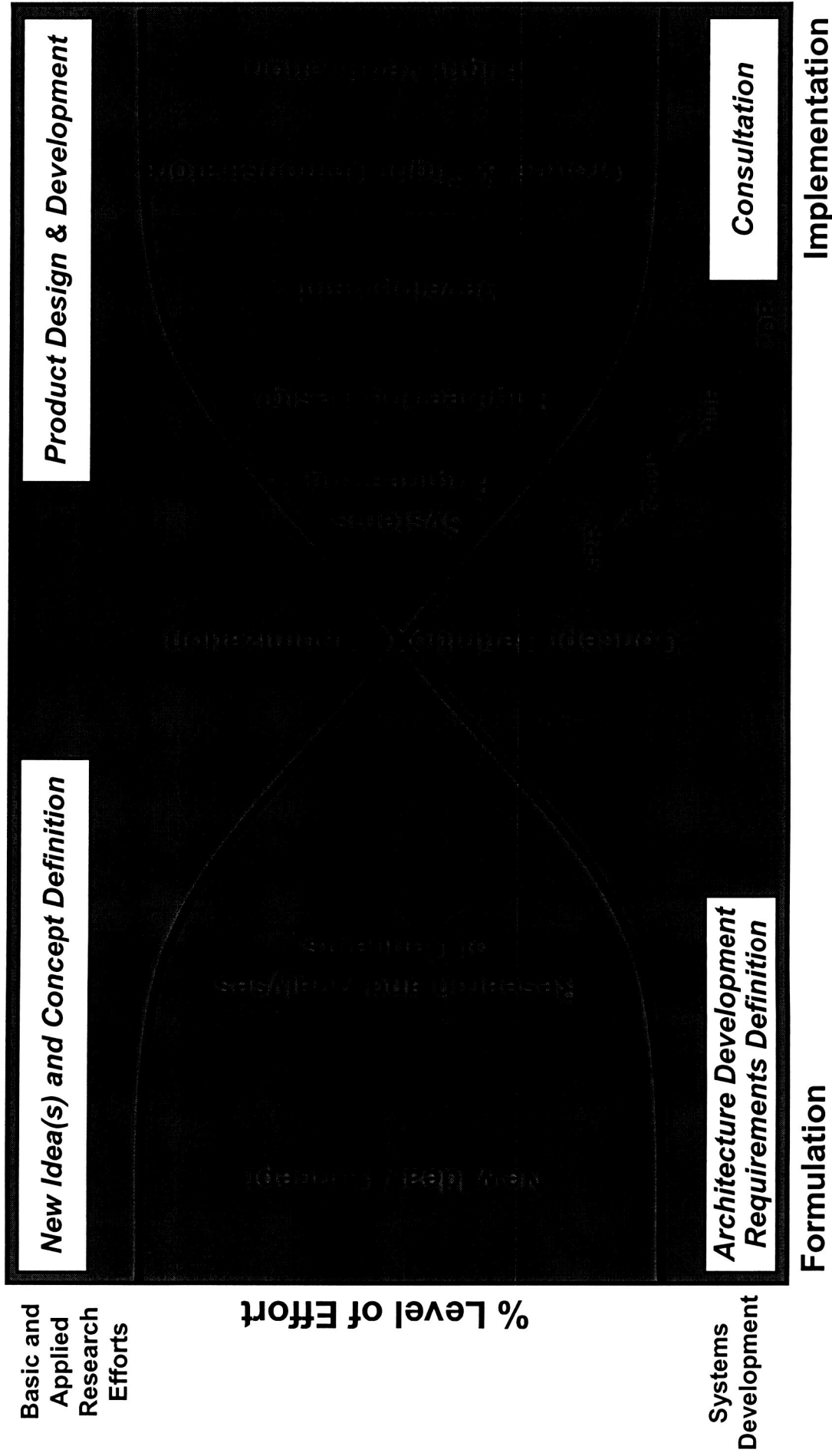
◆ Reliability

- Must assure very high reliability to minimize the risk of losing capital investments and life
- More energetically stressed systems require special attention (particularly materials issues)

◆ Affordability

- Affordability is related not only to hardware development costs but operations costs as well
- Despite the risks, it is the paradigm shifts of expanded capability that generally offer more savings

Flow of Advanced Research Effort (TRL 1-3) into Design and Development (>TRL 5)



Advanced Space Propulsion Research Goals & Objectives

- Conduct Basic & Applied Research in support of NASA's space propulsion needs
 - Address TRL 1 – 3
 - Coordinate research and develop coherent strategic plan for advancing beyond today's capability
 - Establish research linkage to space propulsion technology customer needs
- *Produce the science and technology to enable commercial ventures and voyages that are not currently feasible*
 - Safe, low-cost, routine space access
 - Short-duration, on-demand travel throughout the solar system and beyond
 - High Specific Energy/Power Propulsion is an enabling research focus
- *Demonstrate scientific proof-of-principle of extremely high specific energy/power concepts and enabling propulsion technologies*
- *Conduct fundamental feasibility assessments of new technologies which might enable exciting new missions.*
- *Work closely with NGLT, In-Space, and NSI programs as well as Space Architect to mature emerging propulsion technologies when appropriate as Low TRL Feeders*
- *Promote a culture of "excellence in research" – Demand Good Science*

"Pick a destination – any destination – for whatever reason. There are two fundamental things that limit us right now. There is not a way to get there in any period of time that would allow contemporary use of the information that would be obtained ..." – Sean O'Keefe, March 2002

Strategic Focus for Space Propulsion Research

◆ Proposed Strategic Focus

- *Emphasis on longer-term, higher-risk, higher-payoff technologies*
 - Fill the technology gap
 - Maintain balanced investment portfolio (avoid premature down-selection)
 - Investments rooted in sound technical analysis (performance & cost)
 - Demonstrate scientific feasibility, mature technologies (TRL 4), and transition to Customers
 - Encourage widest possible dissemination of scientific results
- *Enhance and develop NASA in-house capabilities*
 - To perform world-class scientific research & maintain core competency
 - To effectively manage advanced propulsion research activities across the agency for customers needs
- *Utilize unique external expertise and facilities (avoid duplication of existing capability)*
 - DoD/DOE Laboratories & support of IPA's where appropriate
 - Universities (primarily grants)
 - Private Sector (contracts & SBIR's)
- *Stimulate education, extend graduate research opportunities and ensure consistency with **Competitive Sourcing** mandate*
 - Coordinate with new Education Enterprise
 - Competitive NRA's directed at selected emphasis areas

Technical Focus for Space Propulsion Research

♦ Proposed Technical Focus — High Specific Energy/Power Propulsion

- High Specific Thrust/Power
 - highly energetic reactions / off-board resources / ultra energy storage & power conversion
- High Temperatures & Electromagnetics
 - plasma sciences / high temperature technologies / plasma accelerators / MHD / components
- Non-Chemical Energy Sources
 - beyond NSI , MW electric, advanced fission systems, isomers, fusion, antimatter
- Continued Support of Advanced Chemical Research
 - high energy density fuels / advanced cycles

♦ Seek Revolutionary Breakthroughs & New Scientific Discoveries

- Gamebreakers

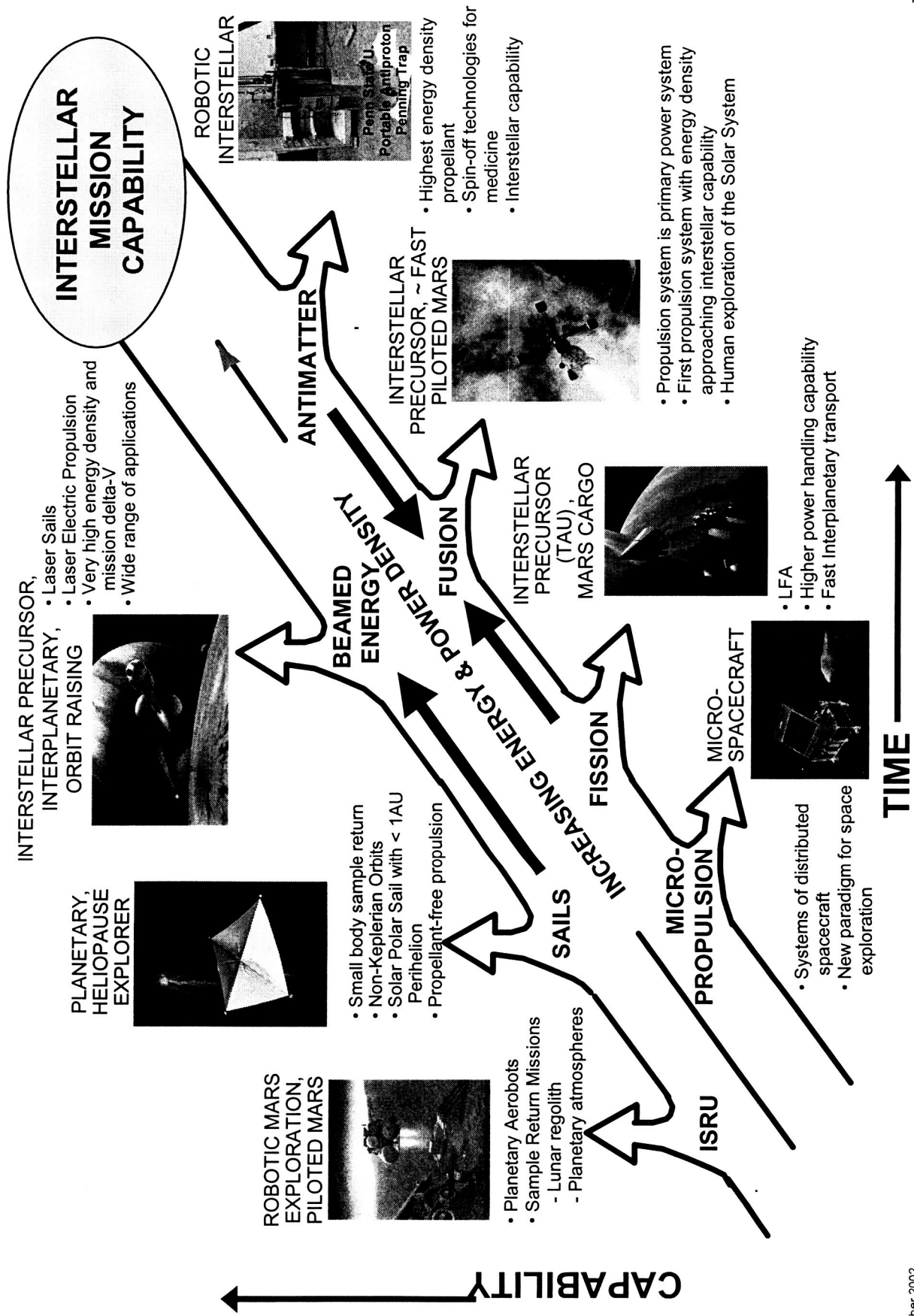
Every so often a major breakthrough occurs that spawns a new technology.

But it will never be found if we aren't looking.



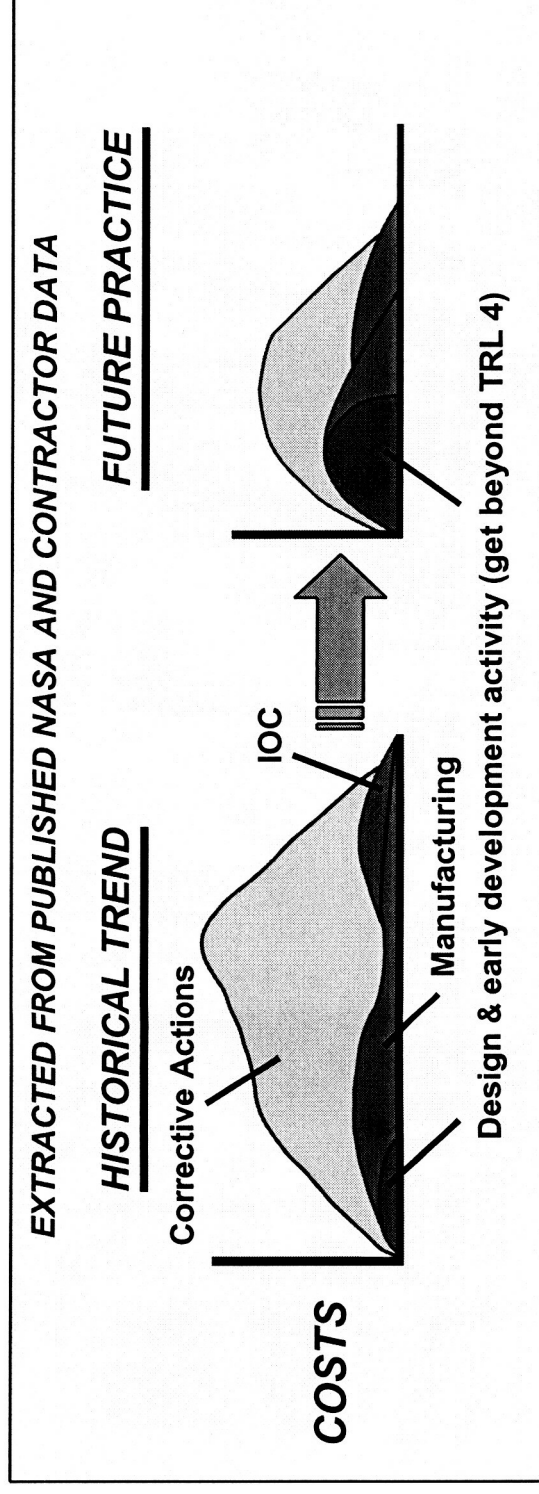
Pythagoras > Archimedes > Galileo/Copernicus > Newton > Maxwell > Einstein > Heisenberg > What's Next?

The Road to the Stars: "Energetic Propulsion" JPL

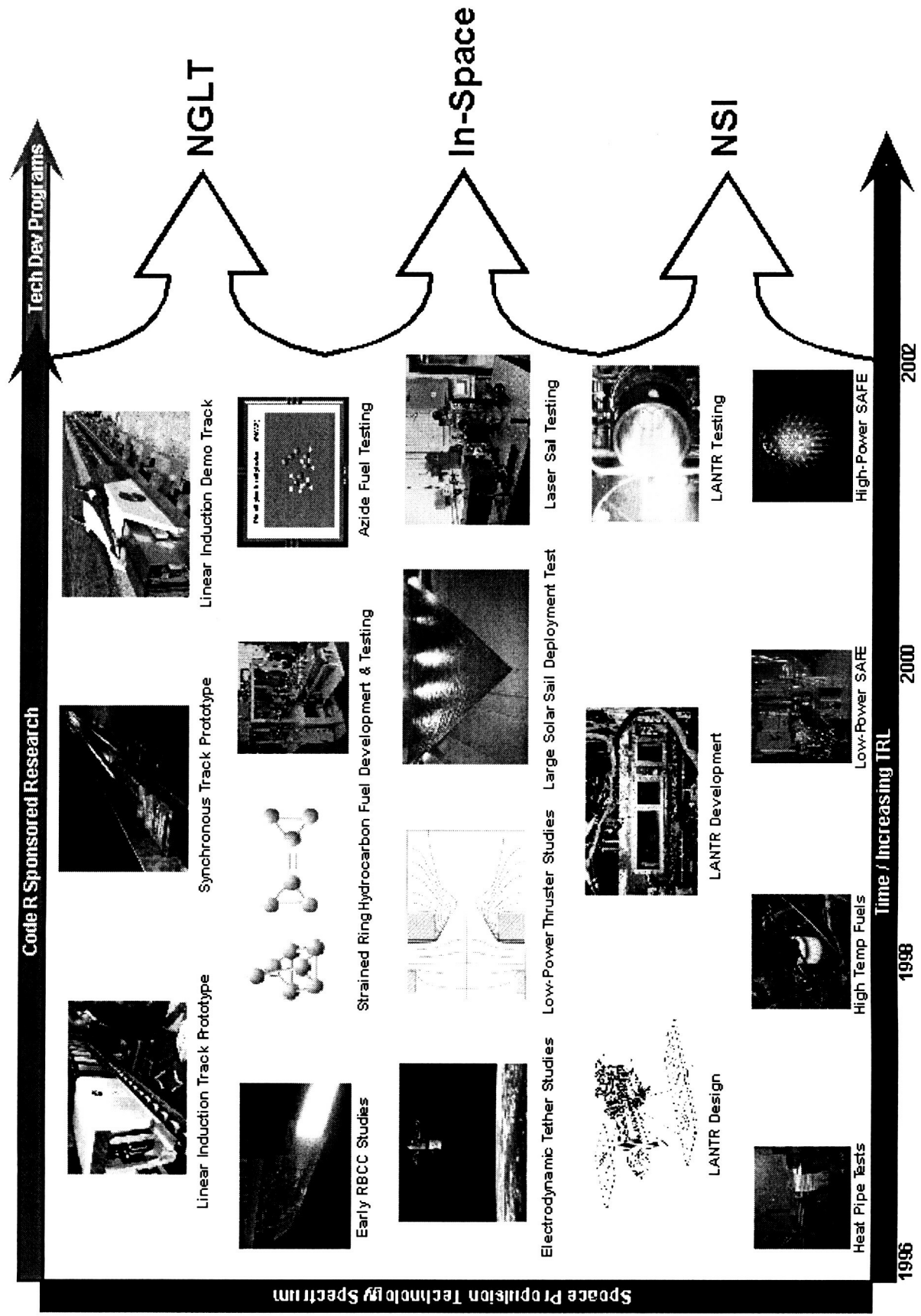


Technical Focus for Space Propulsion Research

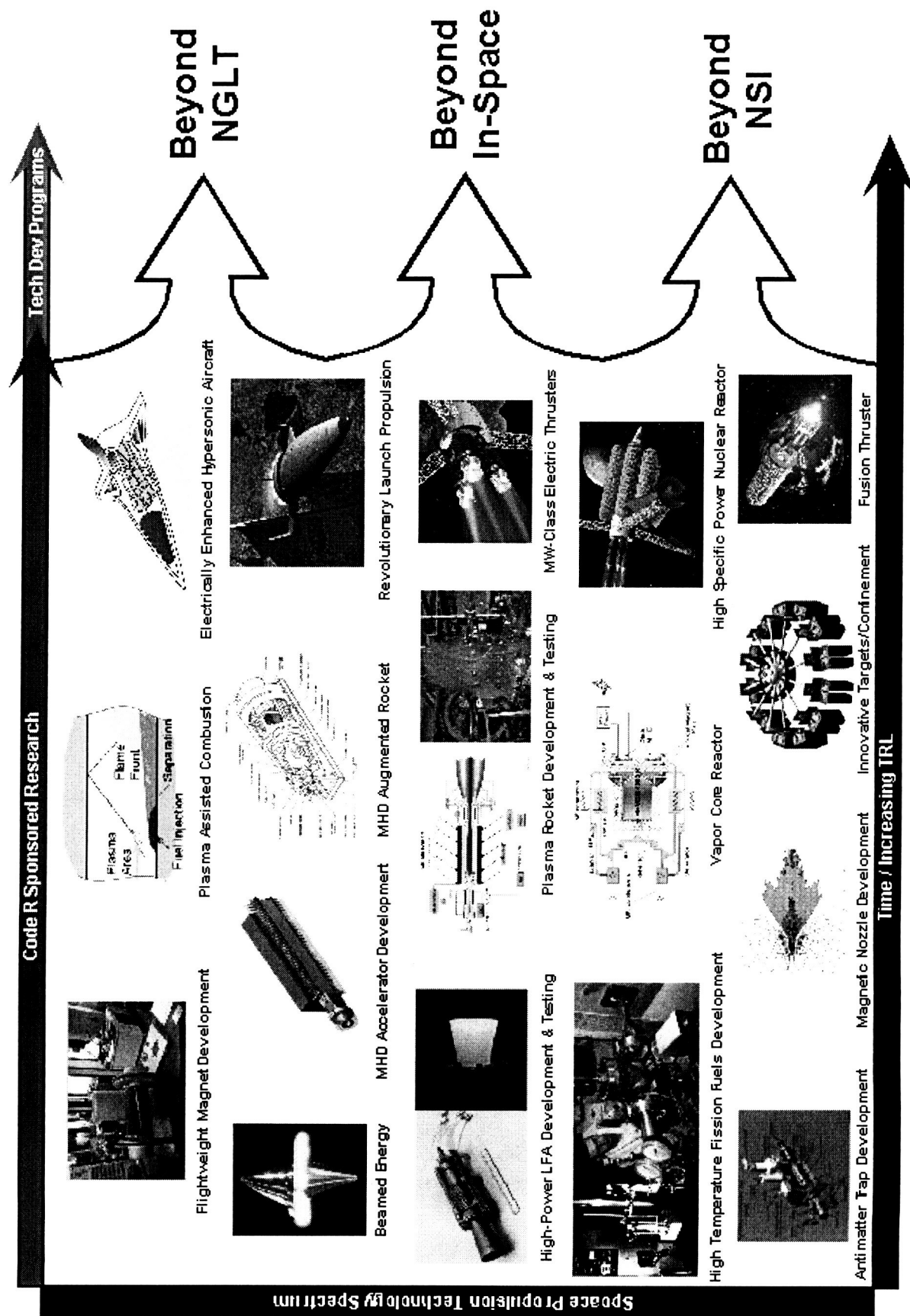
- ◆ **Research should also bridge up the TRL spectrum**
 - Contribute expert technical insight to technology development programs
 - Provide knowledgeable and accurate assessment of emerging technological solutions
 - Resolve recurring technical problems with mature systems
 - Technologies often pressed into operation before full technical understanding established
 - Evolutionary improvements should be based on reliable research and analysis
 - Continue to build a foundation of understanding for existing technologies
- ◆ **Research is the key to reducing total system costs**
 - Typically, the majority of development cost is in “test, fail, fix”
 - Increasing upfront design and research efforts greatly reduce overall program costs



Research & Technology Heritage



Emerging Energetic Propulsion Technologies



Conclusions & Outlook for the Future

- **Propulsion research is consistent with Administrator's vision & focus**
 - Agency emphasis on R&D
 - Strong desire to seek out and develop new enabling technologies that will overcome existing limitations
- ◆ **Space transportation challenges are daunting but avenues of research exist which promise tremendous potential**
 - Fundamentally, it is a problem of “*energetics*”
 - Need high specific energy/power systems
- ◆ **A good strategy has been developed for addressing these challenges**
- ◆ **On-going interactions with NASA HQ to organize and structure advanced space propulsion research activities within the Aerospace Technology Enterprise**